Rec'd PCT/PTO 21 DEC 2004
10/517325

Title: Method and Apparatus for Measuring the Thickness of Compressed Objects

FIELD OF THE INVENTION

This invention relates in general to a method and apparatus for measuring the thickness of compressed objects, and more specifically relates to a method and apparatus for determining the degree of deflection of a breast compression plate in a mammography apparatus.

BACKGROUND OF THE INVENTION

In conventional mammography, a woman places her breast on a breast support plate. A detector is typically mounted under the breast support plate. This detector is sensitive to x-rays. A breast compressor plate that is transparent to light and x-rays presses against the top of the breast to flatten it and to prevent any movement during the mammography process. An x-ray source is then turned on to image the breast, which is between the breast support plate and the breast compression plate.

The transmitted x-ray intensity through the breast is dependent on both the composition of the breast and its local thickness. Most current mammography machines have thickness indicators, which are imprecise. These thickness indicators do not show true breast thickness if either the breast support plate or the compression plate bend or flex. This, in turn, will affect the accuracy and precision of the images of the breast obtained.

Techniques for determining the degree of flex of the breast compression plate have been devised. For example, see Burch, A. and Law, J., *A Method for Estimating Compressed Breast Thickness During Mammography*. Br J Radiol 68, (1995) 394-399, which discloses using the magnification of lead markers placed on top of the compression plate. However, this method requires that all the markers be shown in the image, and does not measure the flexing of plastic plates.

Accurate measurement of compressed breast thickness is an important factor in determining volumetric breast density. It is also an

important factor in determining dose calculation (for example, Wu. X., Gingold E. L. Barnes G. T,, Tucker D m Normalized average glandular dose in Mo/Rh and Rh/Rh target-filter mammography radiology 1994 193 at 83 to 89; Law, J., editor: *The Commissioning and Routine Testing of Mammographic X-ray System*, Institute of Physical Sciences in Medicine, York UK, (1994) 59; Dance, D.R.: *Monte Carlo Calculation of Conversion Factors for the Estimation of Mean Glandular Breast Dose*, Phy Med Biol, 35, (1990) 1211-1219. The measurement of actual thickness provided by commercial mammography can be as much as one centimeter off the actual thickness due to deflection of the breast compression plate.

Accordingly, a mammography apparatus and method that improves the accuracy of measuring breast thickness is desirable.

SUMMARY OF THE INVENTION

An object of an aspect of the present invention is to provide an improved method of determining a degree of deflection in a breast compression plate.

In accordance with an aspect of the present invention, there is provided a method of determining a degree of deflection in a breast compression plate of a mammography apparatus. The mammography apparatus further includes an optical measuring device. The method comprises: (a) providing a pattern on the breast compression plate, the pattern being imagable by the optical measuring device, and having a plurality of local pattern indicia; (b) adjusting the breast compression plate to a selected height; (c) imaging the breast compression plate using the optical measuring device to provide an image of the pattern, the image having a plurality of local image indicia including an associated local image indicia for each local pattern indicia in the plurality of local pattern indicia; and (d) for each local pattern indicia in the plurality of local pattern indicia, determining an associated local deflection of the breast compression plate from the associated local image indicia.

An object of a further aspect of the present invention is to provide an improved mammography apparatus for imaging breasts.

In accordance with a further aspect of the present invention, there is provided an apparatus comprising (a) a breast compression plate for compressing a breast to be imaged, the breast compression plate having a vertical adjustment means for adjusting the height of the breast compression plate to a selected height, and an optically-readable pattern; (b) a breast imaging means for imaging the breast compressed by the compression plate; (c) an optical measurement means for generating an image of the optically-readable pattern; and, (d) calculating means for determining a deflection of the breast compression plate from the selected height from the image of the optically readable pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of preferred aspects of the invention is provided herein below with reference to the following drawings, in which:

Figure 1, in a perspective view, illustrates a mammography machine in accordance with the preferred embodiment of the present invention;

Figure 2 is a schematic drawing showing the optical axis of a CCD (Charge-Coupled Device) camera, and the orientation of this optical axis relative to a horizontal plane having a grid-like pattern;

Figure 3, in a schematic view, illustrates the optical pattern of one of these squares of the pattern of the horizontal plane of Figure 2;

Figure 4, in a graph, plots the pattern shift of different rows of the grid pattern of Figure 2 against thickness; and,

Figure 5 in a three-dimensional graph, plots thickness in centimeters against grid column and row location.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

Referring to Figure 1, there is illustrated in a perspective view, a mammography machine 12. The mammography machine 12 includes a breast support plate 14, a breast compression plate 18, an x-ray tube 16 and a camera 20. In operation, the x-ray tube 16 projects x-rays through the breast compression plate 18, which is transparent to light and x-rays, through the breast, and through the breast support plate 14. The breast compression plate 18 may be vertically adjusted to accommodate breasts of different dimensions. The breast support plate 14 includes a detector (not shown) that is sensitive to the x-rays. Variation in the density of the breast will have an effect on the x-rays traveling through the breast, which will affect the image left on the detector in the breast support plate 14. These signal variations may then be examined for possible tumors or other conditions. As discussed above, the transmitted x-ray intensity through the breast depends both on the composition of the breast and the thickness of the breast. Accordingly, to properly interpret the image, the thickness of the breast must be known. To accurately know the thickness of the breast, the deflection of the breast compression plate 18 must also be known. Deflection of the breast support plate 14 is much less of a concern, as this plate is comparatively rigid.

According to an embodiment of the present invention, a grid-like pattern is provided on the top of the breast compression plate 18. Referring to Figure 2, the orientation of this camera 20 is shown relative to a grid-like pattern 22 on the upper side of breast compression plate 18. The camera 20 has an optical axis 24 that forms an angle α relative to the vertical axis 26 normal to the horizontal plane of the breast compression plate 18 bearing the grid-like pattern 22. As will be apparent to those skilled in the art, when the grid-like pattern 22 is moved up or down the vertical axis, this will change the image of each intersection point 28 generated by the camera 20. This is illustrated in more detail in Figure 3 with respect to one square of the grid-like pattern 22, and specifically with respect to point 28_0.

Referring to Figure 3, there is illustrated in a not-to-scale schematic view, how the image on the camera changes based on flexion or other vertical movement of the breast compression plate 18. The location of the lens of the camera 20 is marked 20a in Figure 3. A line of sight 30 connects intersection point 28_0 with lens location 20a. This line 30 is then extended to an image plane 32. The intersection of the line 30 with the image plane 32 marks the image point 34_0 corresponding to intersection point 28_0. The intersection point 28_0 is displaced from the optical axis by an initial distance A. The angle between line of sight 30 and optical axis 24 is θ_2.

Say that the breast compression plate 18 is flexed upwardly by a breast compressed between the breast compression plate 18 and the breast support plate 14. This upward displacement will vary from intersection point 28 to other intersection points 28 based on fluctuation in breast thickness and compressibility. However, for the particular intersection point 28_0 with which Figure 3 is concerned, the deflection is by an amount T in a direction normal to the horizontal plane of the breast compression plate 18. As a result of the deflection of intersection point 28_0 to a new position shown as 28_d, a new line of sight 36 to the lens position 20a is generated. When extended back to the image plane 32, this line of sight 36 intersects at new image point 34_d. This new image point 34_d is a shift S from the initial image point 34_0 and is displaced from the optical axis 27 by a distance S_0. Line of sight 36 is at an angle θ_1 to optical axis 24.

As shown in the drawing, the lens position 20a is defined by angle α, as well as by distances L and L_0, both of which distances are measured parallel to the optical axis 24. Distance L is the distance from the camera lens 20a to the plane of the displacement point 28_0. L_0 is the distance from the camera lens 20a to the image plane 32. The parameters T_0, S_0 and θ_2 are fixed relative to each intersection point 28, although these parameters change for different intersection points 28. The parameters θ_1, S and T change depending on the degree of flexing of the breast compression plate. However, as shown below, the thickness T varies linearly with the shift S.

From trigonometry, $\tan(\theta_2) = A/L = (S_0 - S)/L_0$ and $\tan(\theta_1) = [A + T_0 * \tan(\alpha)]/(L - T_0) = S_0/L_0$

$$A/L = (S_0 - S)/L_0 \qquad (1)$$

and

$$[A + T_0 * \tan(\alpha)]/(L - T_0) = S_0/L_0 \qquad (2)$$

Finally, based on trigonometry and then solving for T_0 using equations (1) and (2)

$$T = T_0/\cos\alpha = S(L/L_0)[S_0\cos\alpha/L_0 + \sin\alpha] \qquad (3)$$

These results were also verified empirically by changing the position of the breast compression plate. The shift of grid marks on the image plate was then mapped as a linear function of the height of the breast compression plate 18 for each X, Y coordinate of the grid pattern. Referring to Figure 4, the relative shift for intersection points 28 in a first row 22a, a third row 22b and a fifth row 22c of the grid pattern 22 are shown. Clearly, θ_2 increases with the horizontal distance from the camera such that for the fifth row 22c θ_2 is larger than θ_2 is for the first row 22a. θ_2 for the third row 22b is smaller than θ_2 for the fifth row 22c, and is larger than θ_2 for the first row 22a. As a result, the shift S for intersection points 28 in the fifth row 22c will be greater than the shift S for intersection points 28 in the first row 22a. However, in both cases there is a linear relation between the shift S and the thickness T. This is clearly reflected in the lines plotted in the graph of Figure 4. Accordingly, the thickness at an individual intersection point 28 can be computed from an image of the grid pattern 22 taken along with each mammographic study.

Referring to Figure 5, there is illustrated in a three-dimensional graph, a thickness map. The thickness map plots the displacement between the breast compression plate 18 and the breast support plate 14 at different X and Y positions on the grid. This displacement can be determined from the image of the grid at these X and Y positions in accordance with the above-described method.

Other variations and modifications of the invention are possible. For example, other non-grid patterns may be provided on the top of the breast compression plate to enable its deflection to be determined. All such applications, modifications or variations are believed to be within the sphere and scope of the invention as defined by the claims appended hereto.